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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION AT TRANSONIC SPEEDS OF A JET CONTROL ON A 35° SWEPT WING

TRANSONIC-BUMP METHOD

By Raymond D. Vogler and Thomas R. Turner

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WIND-TUNNEL INVESTIGATION AT TRANSONIC SPEEDS OF A JET CONTROL ON A 35° SWEPT WING

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SUMMARY

An investigation was made in the Langley high-speed 7- by 10-foot tunnel by means of the transonic-bump method to determine the characteristics of a jet control consisting of numerous holes normal to the wing surface located at the 65-percent chord line of a 35° swept semispan wing with an NACA 65A006 airfoil section. The Mach number range was from 0.60 to 1.15, the angle-of-attack range was from -4° to 16°, and ejection-pressure ratios were as high as 9.7 to 1 between the static pressure in the plenum chamber and free-stream static pressure.

The rolling-moment coefficient usually varied almost linearly with the momentum coefficient and, at subsonic speeds, smaller jet holes usually were more effective than larger jet holes for a given momentum coefficient. The control was more effective in producing rolling moments at low angles of attack than at high angles of attack at subsonic speeds but was more effective at high angles of attack than at low angles of attack at $M = 1.15$. The momentum coefficients for the range investigated had little effect on the longitudinal stability. Drag coefficients for a given lift coefficient were negligibly affected by the jet control at $M = 1.15$ but were increased at lower Mach numbers. The total change in lift coefficient produced by the control was two to five times larger than the calculated change produced by jet thrust only.

INTRODUCTION

The growing need for simplified airplane and missile controls operating with lower actuating forces than now required has aroused considerable interest recently in the possibility of using air jets as controls. An investigation (ref. 1) has indicated that air ejected normal

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to a wing upper surface will act as a spoiler thus reducing the lift of the wing. Jet controls operated by stream ram air for missile control have recently been investigated (ref. 2) and the use of ram air as an emergency control on airplanes at low speeds is discussed in reference 3.

The purpose of the present investigation was to determine rolling-moment characteristics of a jet control on a 35° swept wing using compressed air at various pressures. The control was located at the 65-percent chord line which may not have been the optimum chordwise position. Some effects of changing the jet hole diameter and the spacing between jet holes were determined. The investigation was made in the Langley high-speed 7- by 10-foot tunnel using the transonic-bump method to obtain Mach numbers from 0.60 to 1.15. In addition to the rolling-moment characteristics, lift, drag, and pitching-moment characteristics were obtained through an angle-of-attack range from -4° to 16°.

SYMBOLS AND COEFFICIENTS

The forces and moments measured on the model are presented with respect to an orthogonal system of axes. The longitudinal axis is parallel to the free air stream and the lateral axis is in the wing chord plane. The origin of the axes is at the intersection of the root chord and a line that is perpendicular to the root chord and passes through the quarter-chord point of the mean aerodynamic chord.

C_L lift coefficient, $\frac{\text{Twice semispan lift}}{qS}$

C_D drag coefficient, $\frac{\text{Twice semispan drag}}{qS}$

C_m pitching-moment coefficient, $\frac{\text{Twice semispan pitching moment}}{qS\bar{c}}$

C_l rolling-moment coefficient produced by control, $\frac{\text{Rolling moment}}{qSb}$

S twice wing area of semispan model, 0.250 sq ft

q dynamic pressure, $\frac{\rho V^2}{2}$, lb/sq ft

ρ mass density of air, slugs/cu ft

V free-stream air velocity, ft/sec

b twice wing span of semispan model, 1.0 ft

$\bar{c}$ mean aerodynamic chord of wing, 0.255 ft

C_μ momentum coefficient, $\dfrac{wV_j}{gq\frac{S}{2}}$

w quantity of air used in control jets on one semispan, lb/sec

g acceleration of gravity, ft/sec^2

V_j jet velocity associated with isentropic expansion to the critical pressure ratio (0.528) at the jet exit, ft/sec

p_p static pressure in plenum chamber, lb/sq ft

p free-stream static pressure, lb/sq ft

p_e jet-exit static pressure ($p_e = p$ for unchoked flow, $p_e = 0.528p_p$ for choked flow), lb/sq ft

A_j total area of jet holes, sq ft

M Mach number

R Reynolds number

α angle of attack, deg

D jet-hole diameter, in.

The rolling-moment coefficients presented herein represent the effects produced by operation of the control on only one semispan of the complete wing. The lift, drag, and pitching-moment coefficients represent the effects produced by operation of the control on the upper surfaces of both semispans of the complete wing.

MODEL AND APPARATUS

A drawing of the steel semispan model and pertinent information are given in figure 1. The wing had NACA 65A006 airfoil sections parallel to the free air stream. A plenum chamber was located in the wing between the 55- and 70-percent chord lines. Fifty-four jet holes were drilled into the plenum chamber normal to the upper wing surface

along the 65-percent chord line between stations $0.133\frac{b}{2}$ and $0.70\frac{b}{2}$. Sets of holes of two diameters, 0.020 inch and 0.031 inch, were investigated. The holes were approximately 1/16 inch on centers except for a few tests when alternate holes of the larger-diameter group were plugged leaving 27 holes on 1/8-inch centers. A pressure tube was used to obtain static pressure in the plenum chamber.

The model was mounted on an electrical strain-gage balance enclosed within the bump. Compressed air was introduced into the plenum chamber through the channel leading from the wing butt. The amount of air used was measured with a calibrated orifice-type flowmeter. The forces and moments on the model were recorded with calibrated recording potentiometers.

TESTS AND CORRECTIONS

The model was tested in the flow field of a bump mounted on the floor of the Langley high-speed 7- by 10-foot tunnel. The Mach number range was from 0.60 to 1.15 and the angle-of-attack range was from -4° to 16°. There is a small Mach number variation over the wing for a given test Mach number, and charts showing the Mach number gradient over the bump with the model removed are given in reference 4. Compressed air under absolute plenum chamber pressures up to a maximum of approximately 84 pounds per square inch for the smaller holes was ejected from jet holes on the upper surface of the wing.

The variation with Mach number of mean test Reynolds number based on the mean aerodynamic chord is given in figure 2.

No corrections to the data have been applied. The usual wind-tunnel blockage and jet-boundary corrections are considered negligible because of the small size of the model compared to the size of the tunnel test section. Some static tests with jets sealed were made to determine the effect on measured forces of any forces transmitted to the wing by the flexible air hose attached to the wing butt. The effect on the drag was negligible, and the effect on the lift and moments was generally less than 3 percent except where there was a combination of very low aerodynamic forces and maximum pressure in the hose. There is some doubt concerning the applicability of flap-type aileron corrections for reflection-plane models to jet controls; consequently these corrections have not been applied to the data presented. If applied, these corrections would reduce the rolling-moment coefficients at the lowest Mach number approximately 20 percent. Theory indicates that the corrections approach zero as the Mach number approaches 1.0.

RESULTS AND DISCUSSION

The rolling-moment coefficients are presented as a function of momentum coefficient C_μ and, since the quantity of air used is not readily obtainable from the momentum coefficient, the relation between quantity and momentum coefficient is given in figure 3 for the Mach numbers at which most of the data were obtained. It should be pointed out that a full-scale aircraft (30-foot span), flying at conditions corresponding to the highest Mach number of this investigation and at 25,000 feet altitude, would require approximately 34 pounds of air per second to obtain the rolling-moment coefficient obtained in this investigation. The pressure in the jet plenum chamber was sufficient to produce sonic velocities in the jet holes except for some of the test points at the lowest value of C_μ for each configuration.

For most conditions, the rolling-moment coefficients increased almost linearly with momentum coefficients (figs. 4, 5, and 6) throughout the Mach number range investigated. Cross plots of the data of figure 6 indicate that for a given C_μ at low angles of attack the 0.020-inch holes produce larger rolling-moment coefficients than the 0.031-inch holes at Mach numbers less than 1.0 but show little difference above $M = 1.0$ (fig. 7). At subsonic speeds, the rolling-moment coefficients are reduced considerably by increased angle of attack above 4°, but at a Mach number of 1.15 there is an indication that the control is more effective at high angles of attack than at low angles and there is less variation with angle of attack (fig. 7).

When the plenum chamber had fifty-four 0.031-inch-diameter holes, the distance between hole centers was two diameters. A few tests were made with alternate holes plugged so that the distance between centers became four diameters, with the control span remaining about the same. Plugging alternate holes (fig. 7) reduced the rolling-moment and momentum coefficients but not always in the same proportion. At low angles of attack, the rolling-moment coefficients were reduced a greater percentage than the momentum coefficient while at high angles of attack just the reverse occurred.

The aerodynamic characteristics in pitch of the model at very low and at high values of momentum coefficient are given in figure 8 for three Mach numbers. Very little change in the longitudinal stability of the model resulted from increasing the momentum coefficient of the air jets from near zero to the maximum. This increase in momentum coefficient produced an increase in drag coefficient for a given lift coefficient at subsonic speeds, but at $M = 1.15$ the momentum coefficient had little or no effect on the drag coefficient at a given lift coefficient. A portion of the lift loss shown in figure 8 results from the thrust

effect of the jets. This effect at small angles of attack may be approximately calculated by the relation,

$$\text{Thrust} = \frac{wV_j}{g} + A_j\left(p_e - p\right)$$

Calculations indicate that the last term in the above equation for the pressures ($\sim$56 psia) used in the plenum chamber is roughly $0.6 \frac{wV_j}{g}$. Reducing this force to nondimensional form gives a lift coefficient resulting from jet thrust equivalent to $1.6C_\mu$ or 20 to 50 percent of the total change in lift coefficient, depending upon the Mach number.

CONCLUSIONS

An investigation to determine the characteristics of a jet control located on the 0.65-chord line on a 35° swept wing mounted on a bump in the Langley 7- by 10-foot tunnel resulted in the following conclusions:

1. For most conditions, the rolling-moment coefficients produced by the jet control increased almost linearly with jet momentum coefficient, and, for a given momentum coefficient at low angles of attack, a reduction in jet hole diameter usually increased control effectiveness at subsonic speeds but had little effect at Mach number 1.15.

2. At subsonic speeds, the control was more effective in producing rolling moments at very low angles of attack, but at $M = 1.15$ it was more effective at high angles than at low angles of attack.

3. Very little change in longitudinal stability of the wing resulted from increasing the momentum coefficient from near zero to the maximum investigated.

4. The change in lift coefficient produced by the jet control was two to five times larger than the calculated lift coefficient produced by the thrust effect only of the jets.

5. Drag coefficients for a given lift coefficient were little affected by the jet control at $M = 1.15$ but were increased at the lower Mach numbers.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 8, 1955.

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3. Lowry, John G., and Turner, Thomas R.: Low-Speed Wind-Tunnel Investigation of a Jet Control on a 35° Swept Wing. NACA RM L53I09a, 1953.

4. Thompson, Robert F.: Hinge Moment, Lift, and Pitching-Moment Characteristics of a Flap-Type Control Surface Having Various Hinge-Line Locations on a 4-Percent-Thick 60° Delta Wing - Transonic-Bump Method. NACA RM L54B08, 1954.

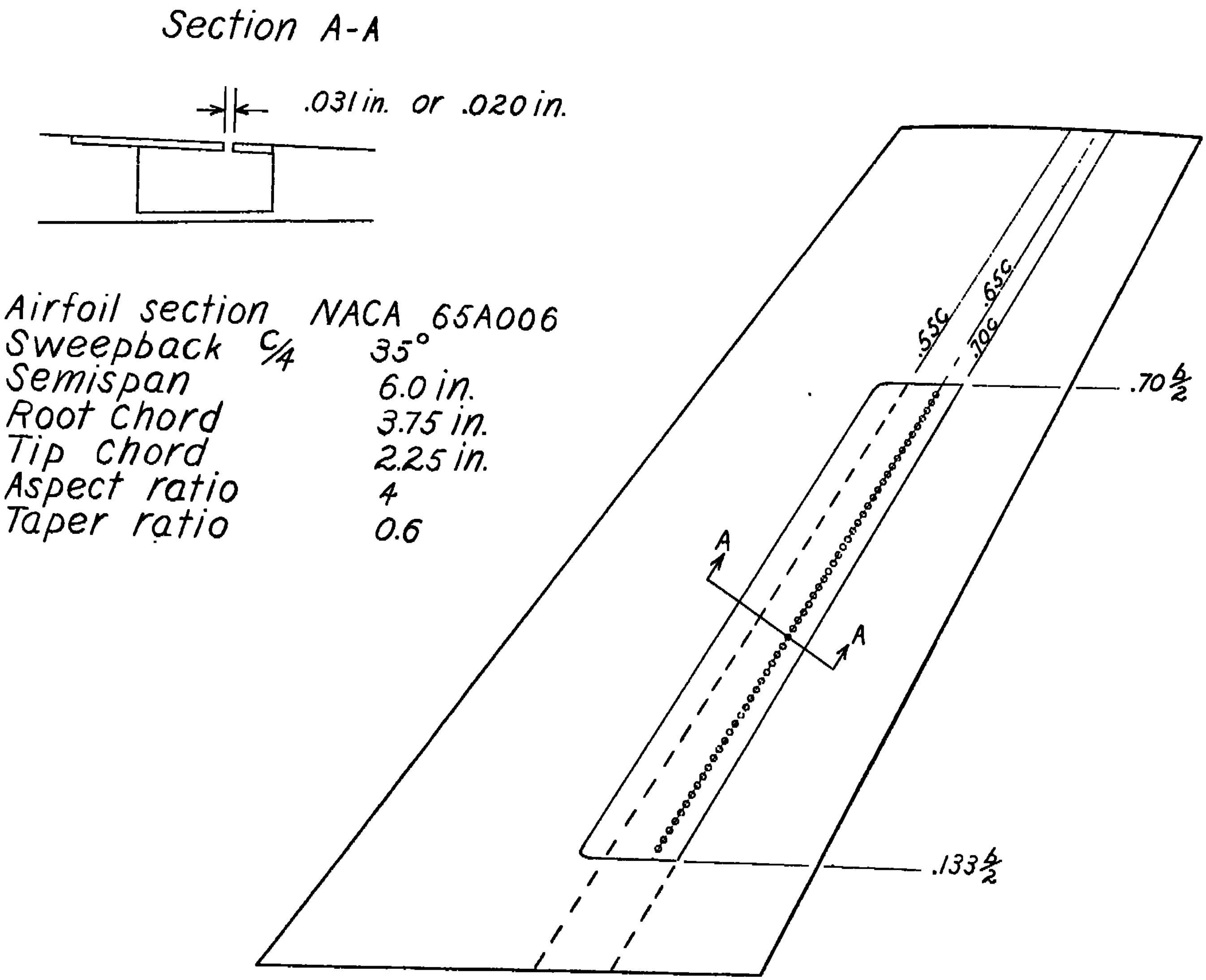


Figure 1.- Model showing jet-control details.

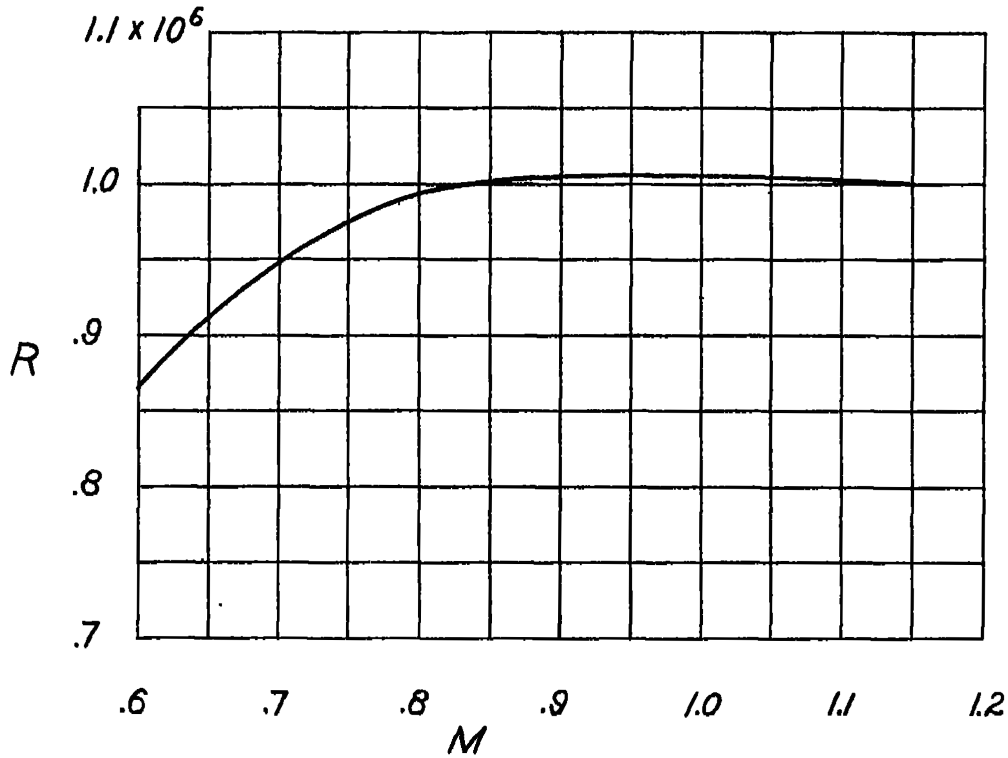


Figure 2.- Variation of mean test Reynolds number with Mach number.

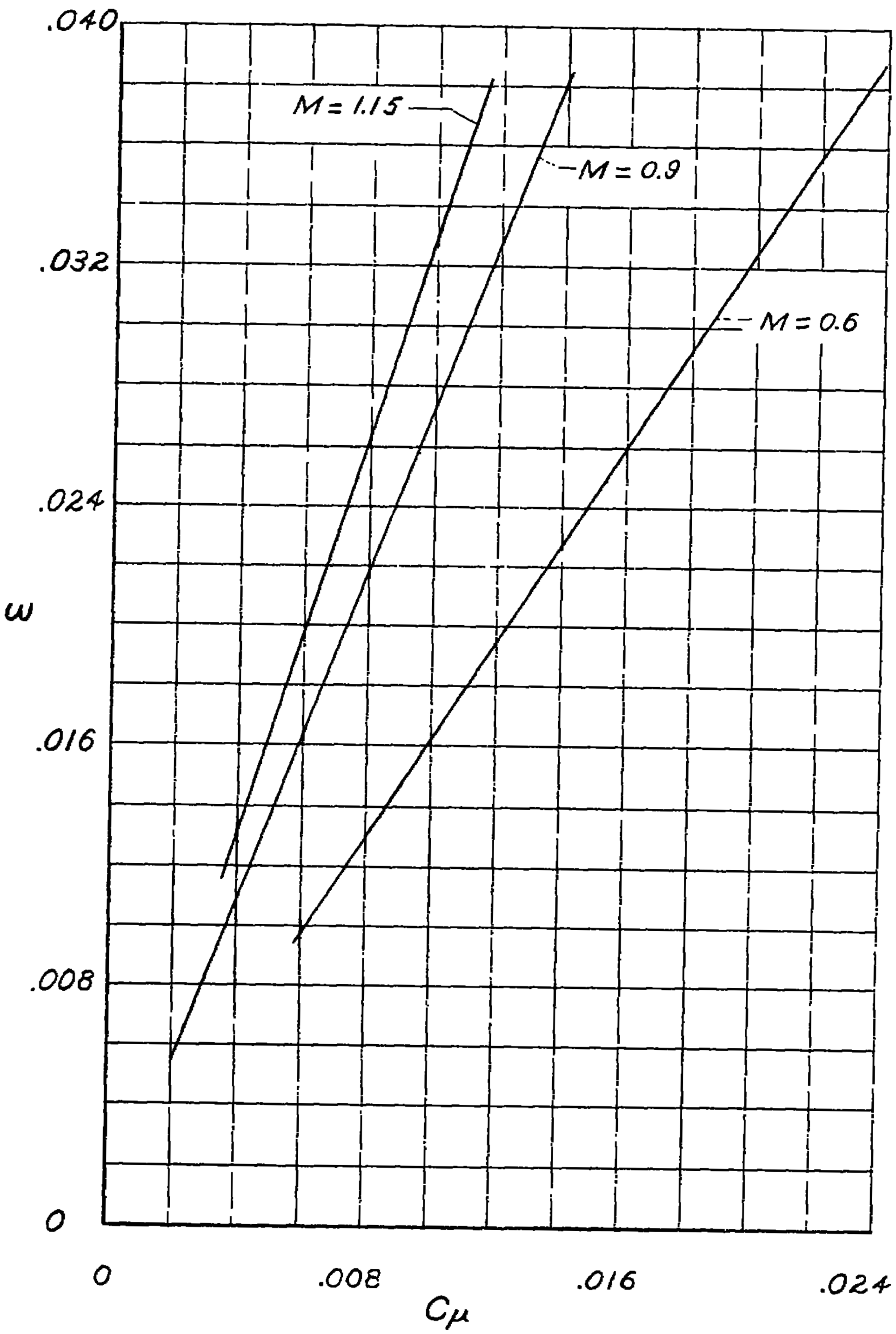


Figure 3.- Relation between quantity of air in pounds per second and momentum coefficient for the control on one wing panel.

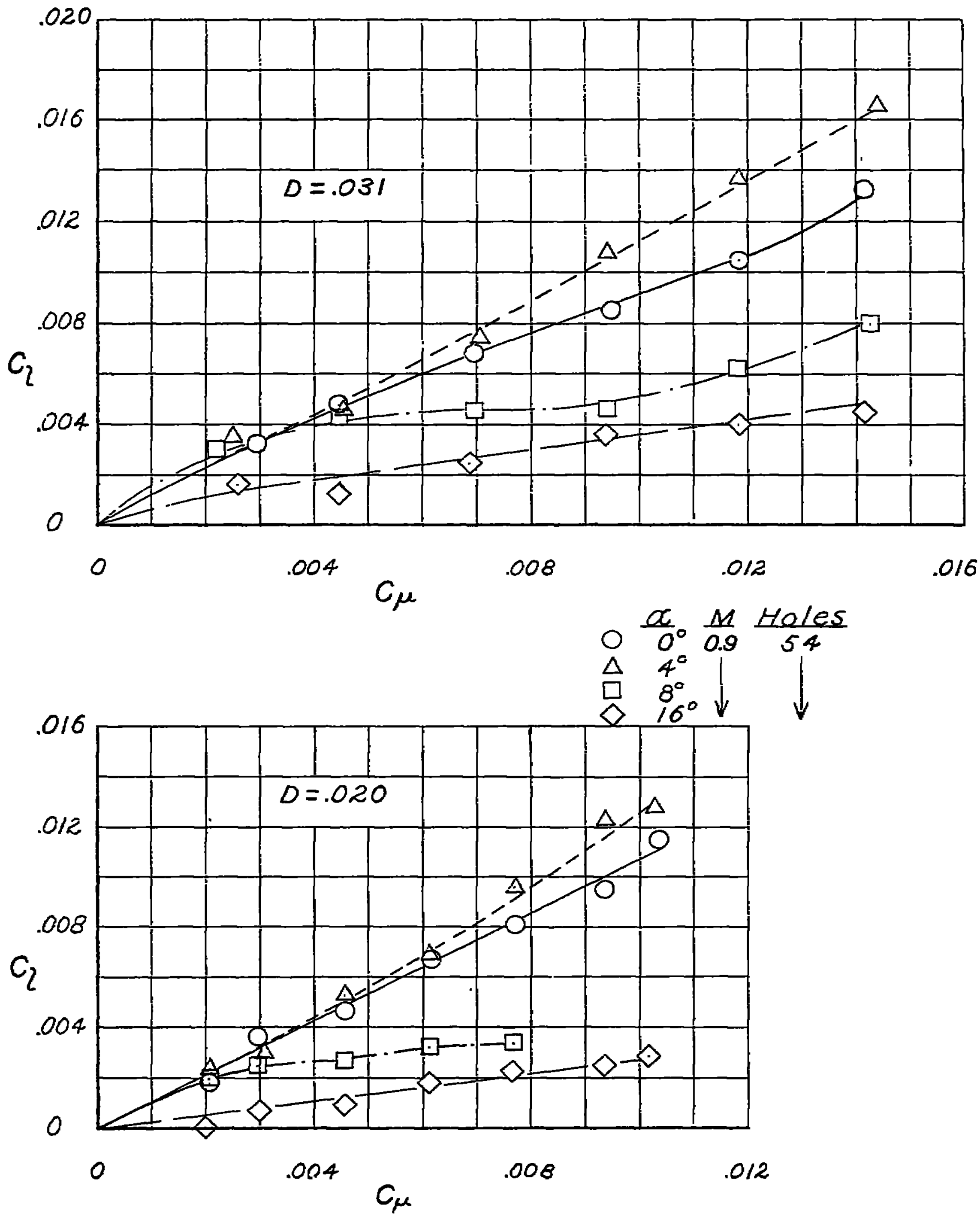


Figure 4.- Rolling-moment-coefficient variation with momentum coefficient for two jet-hole diameters.

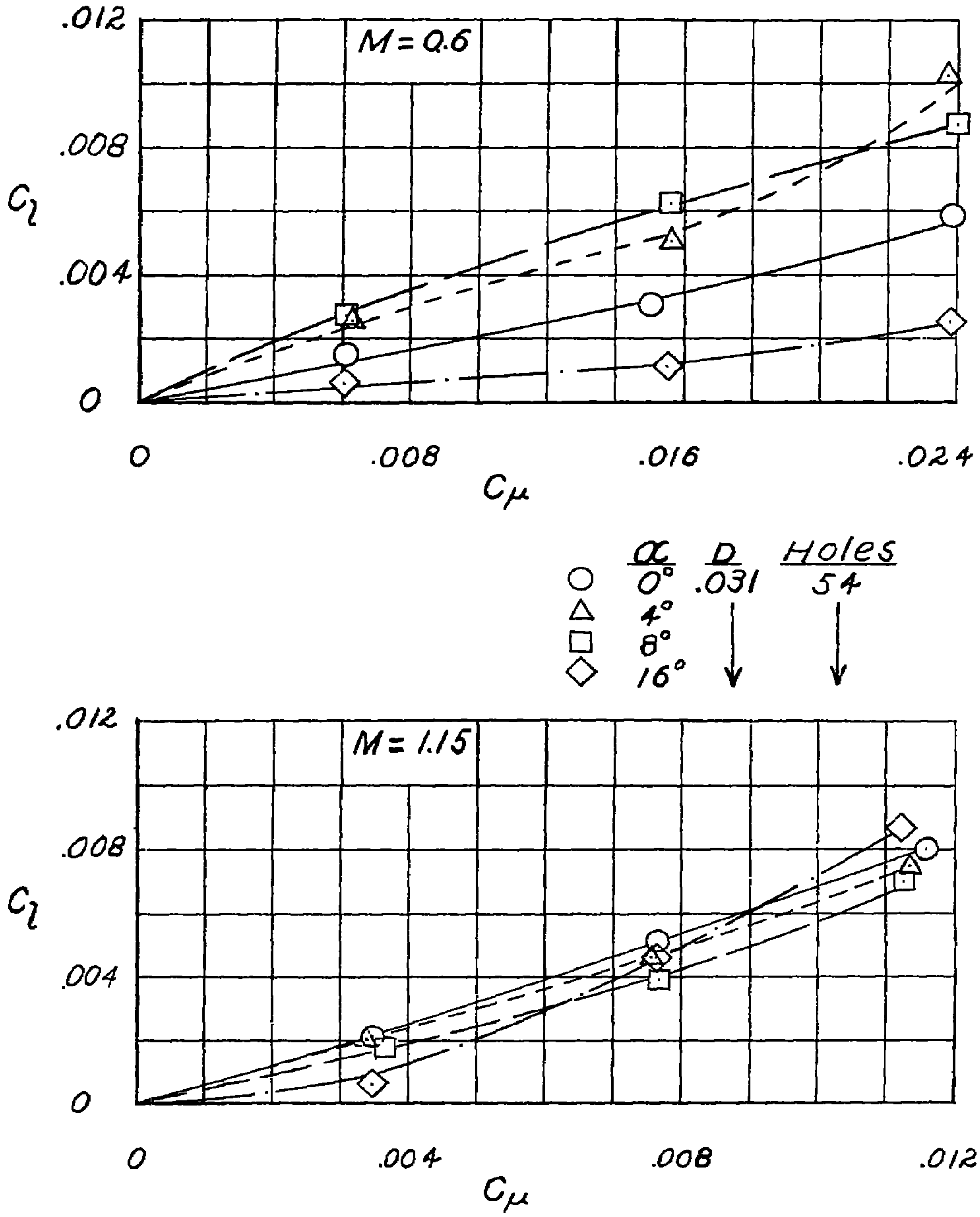


Figure 5.- Rolling-moment-coefficient variation with momentum coefficient at low and at high Mach numbers.

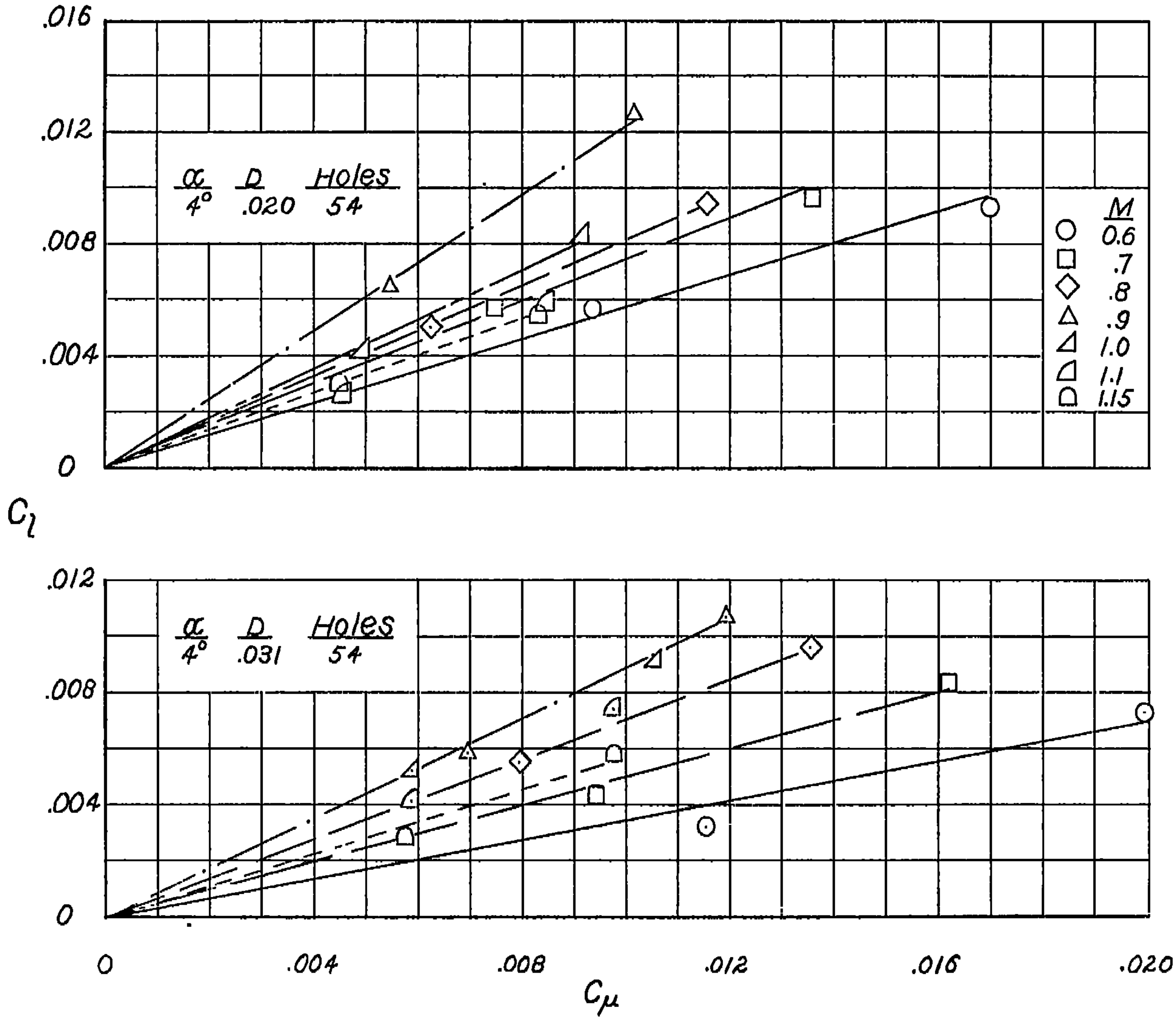
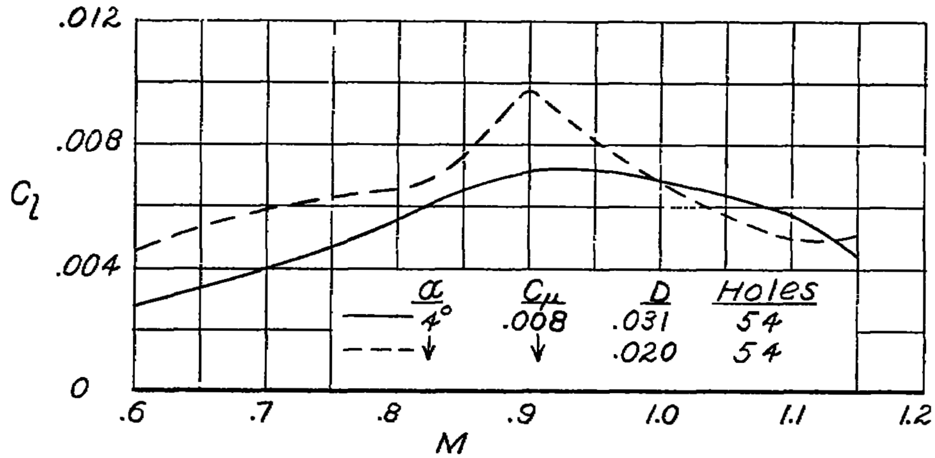


Figure 6.- Rolling-moment-coefficient variation with momentum coefficient at constant angle of attack through the Mach number range.



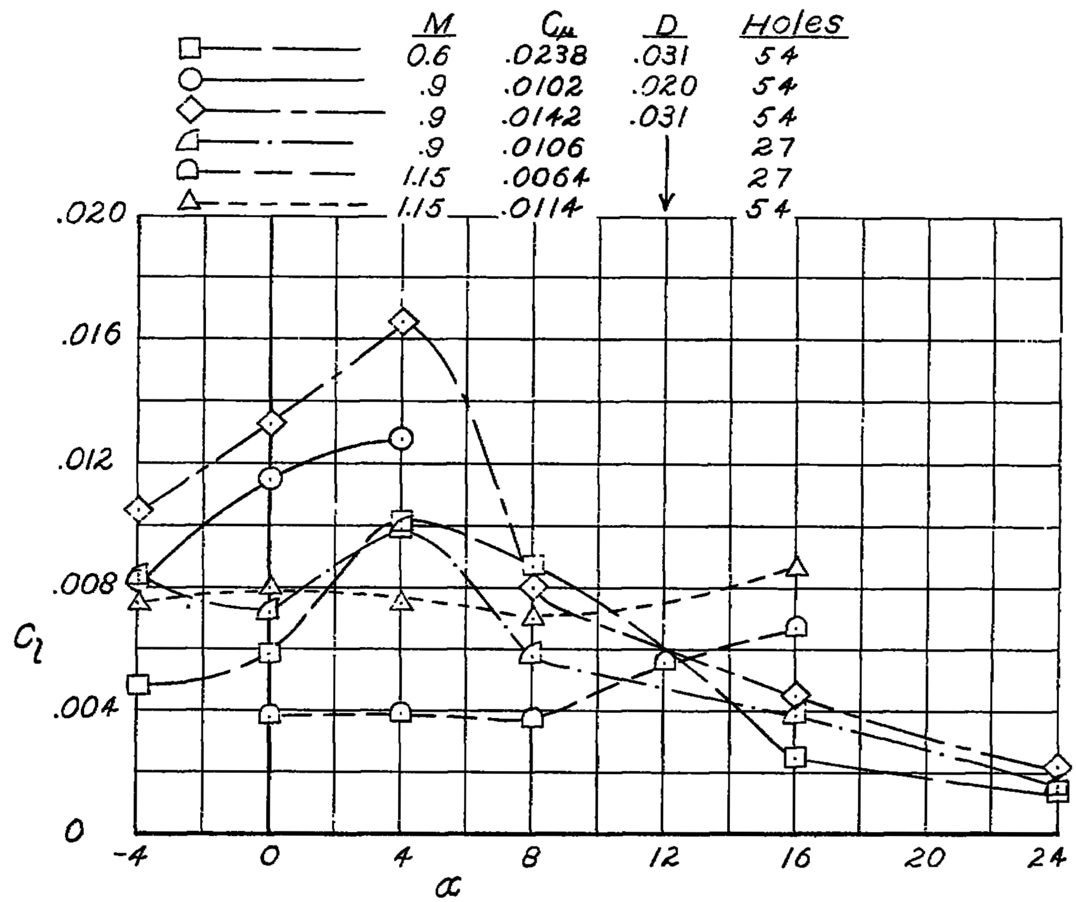
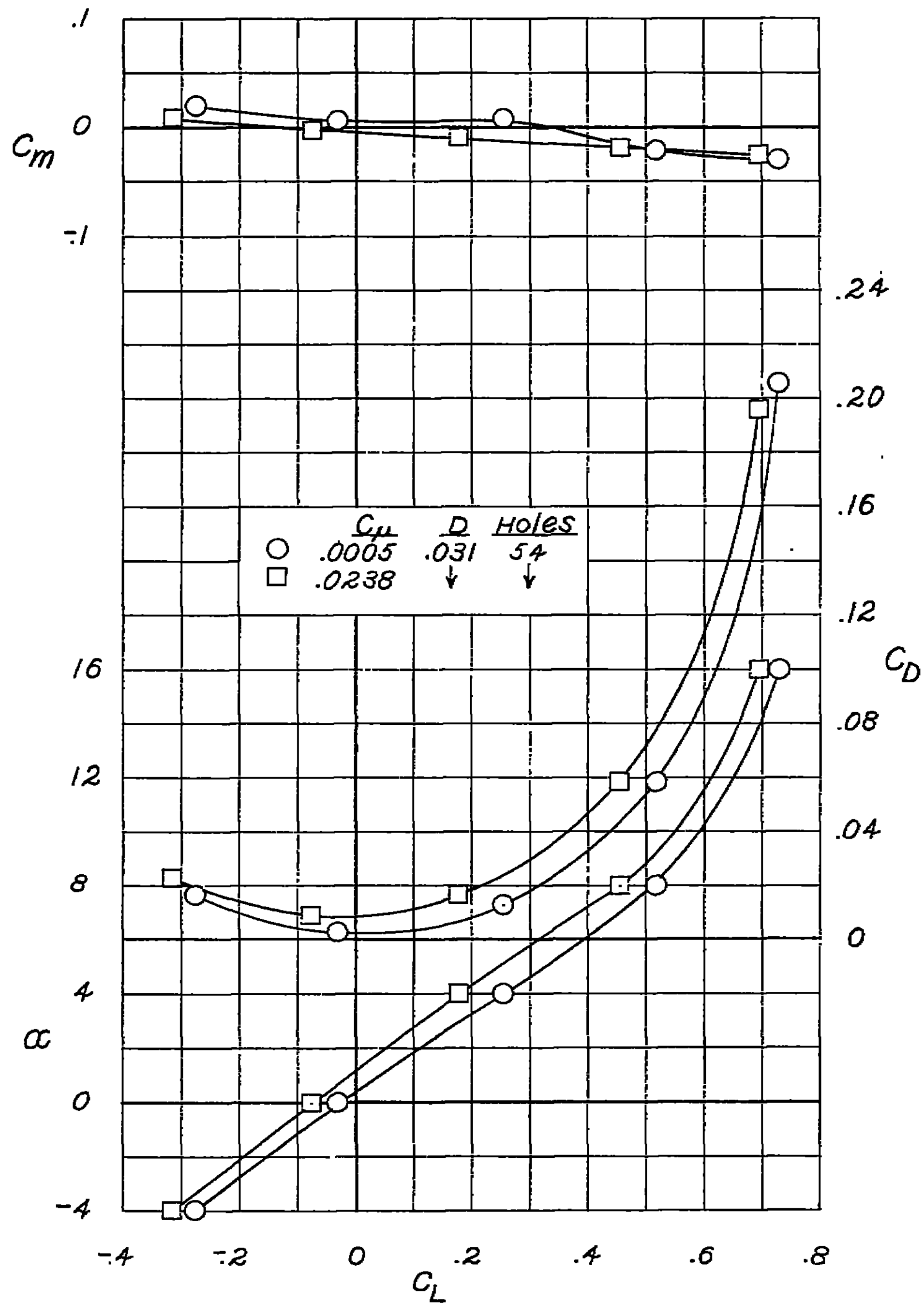
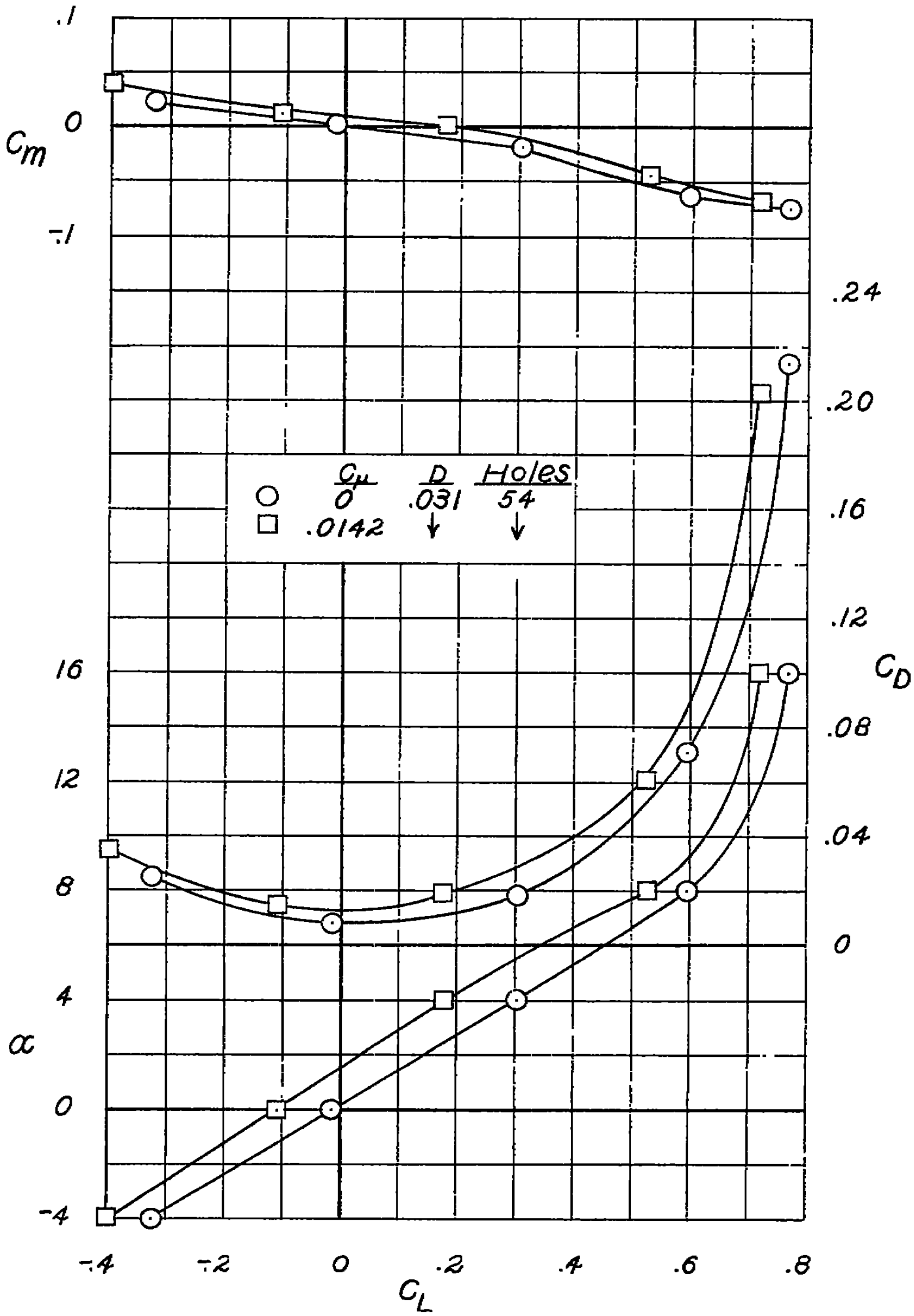


Figure 7.- Variation of rolling-moment coefficient with Mach number and angle of attack.



(a) M = 0.6.

Figure 8.- Aerodynamic characteristics in pitch of the model with jet controls operating on the upper surface of both wing panels.



(b) M = 0.9.

Figure 8.- Continued.

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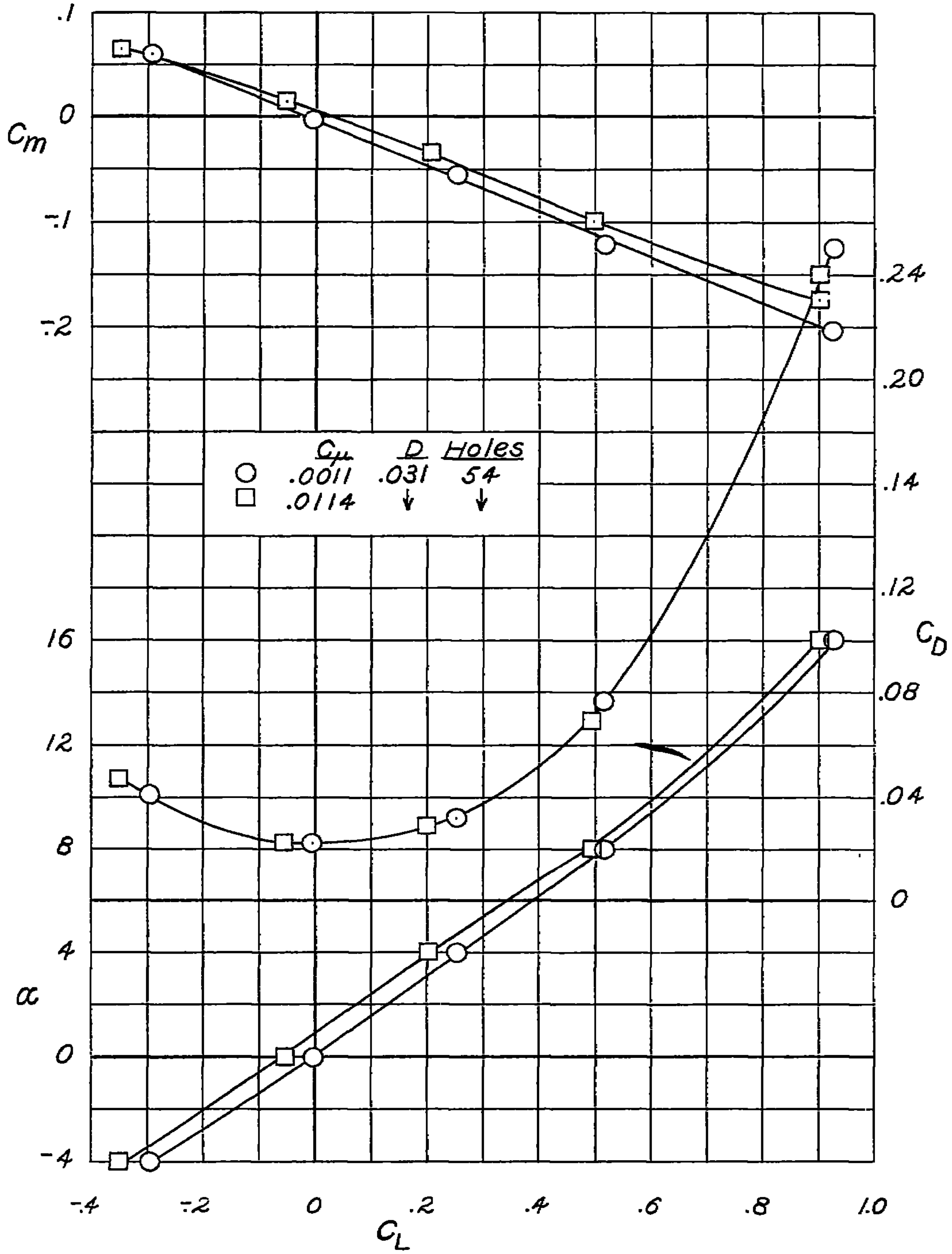

(c) M = 1.15.

Figure 8.- Concluded.